Optical Scatterometry for Fast Evaluation of R2R Processed Structures

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ABSTRACT

Optical Scatterometry measurements were performed on a mold and imprint produced by roll-to-roll UV-assisted nanoimprinting lithography (R2R UV-NIL) in the visible spectral range, and their diffraction efficiencies were calculated. The specimens were imaged by AFM to obtain the topographic parameters of period and height of the periodic structures. Using the AFM-measured and nominal parameters, the diffraction efficiencies of the specimens were modeled employing the RCWA method. Comparing the measured and modeled diffraction efficiencies of the mold and imprint revealed that optical scatterometry was capable of characterizing the topographical structure of the periodic structures, with a high level of confidence.
Keywords: Optical Scatterometry, R2R processing, Metrology

1. INTRODUCTION

Scalable and high-speed manufacturing of optical imprints using roll-to-roll (R2R) processing requires fast metrology techniques capable of evaluating the product on-line to correct for production conditions, if necessary. Optical scatterometry has been shown to be a suitable replacement for time-consuming and expensive conventional methods, like atomic force microscopy (AFM) and scanning electron microscopy (SEM), for characterizing the periodic structures [1, 2]. Every structure has its own unique light diffraction pattern, which is sensitive to its shape and geometrical parameters [3]. By exploiting this phenomenon, fast and accurate evaluation of structures is possible.

In this study, a practical application of optical scatterometry has been investigated by measuring the diffraction efficiencies of R2R-processed specimens and by comparing the results to the modeled diffraction efficiencies that were made using the nominal and AFM-measured parameters.

2. EXPERIMENTAL

2.1. Specimens

Two specimens were investigated. The mold was obtained from Iscent Ltd., Finland, with the nominal period, height and duty cycle of 1200 nm, 100 nm and 50%, respectively. To replicate the mold's pattern onto a PET substrate, a custom system consisting of a R2R platform and a UV-equipped NIL station was utilized. The substrate with a known refractive index was coated with resin and then pressed between a nip roller and the mold. The tension in the substrate was controlled by a load cell. UV lights were used around the roller to cure the resin at the final stage.

2.2. Scatterometry setup

Intensity measurement for the transparent gratings was performed using a linear-aligned setup. A schematic of the system showing the components and their configuration is presented in Fig. 1. A tungsten-halogen light source was used to illuminate the specimen. The light passes through a wire grid polarizer used to orient the electric field of the light perpendicular to the grating lines (TE-polarized). The TE-polarized light then is focused on the backside of the specimens through an objective lens and is diffracted when it interacts with the grating lines. The un-diffracted portion of the light (zeroth-order diffraction) is collected by another objective lens and is guided to a compact CCD spectrometer for analysis. The integration time in this study was 10 s in this static setup to obtain a sufficient amount of data. This time can be reduced to milliseconds, using more efficient CCDs for the in-situ conditions.

Three different measurements are required to calculate the diffraction efficiency of each grating in transmission: two for the intensities of the specimen (I_S) and reference material (I_R), and one for a dark signal (I_D). For the reference intensity measurement, a non-textured area of the same specimen (bare substrate) was used. The dark signal is obtained with

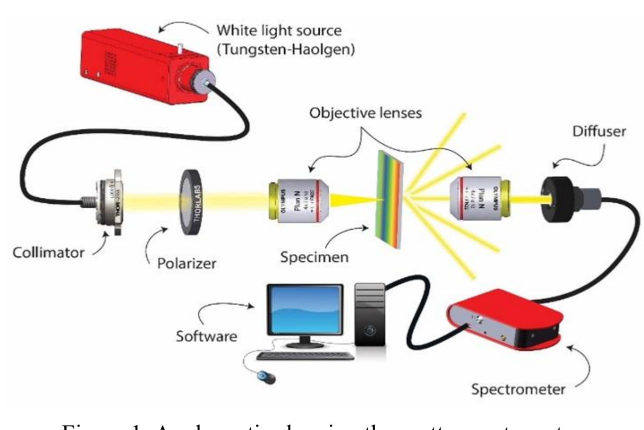

Figure 1: A schematic showing the scatterometry setup.

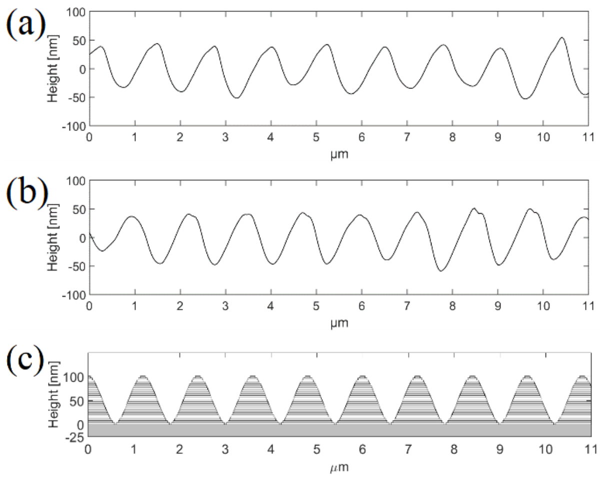

Figure 3: Profiles of the specimens obtain by AFM for (a) mold and (b) imprint, and (c) representative profile of computer modeling.

the light source off to compensate the signal for background light. The diffraction efficiency of the specimen is given by:

$$\eta_{\lambda} = \frac{I_S - I_D}{I_R - I_D} \quad (1)$$

Equation 1 is the relative efficiency since it accounts for the intensity of light diffracted into the order being measured relative to the intensity of light transmitted through a non-textured area of the substrate [4].

2.3. Computer modeling

Simulations of the diffraction efficiencies were performed using the nominal and AFM-measured parameters. The nominal parameters were provided by the mold's manufacturer. AFM imaging was performed with a commercial Bruker AFM, used in tapping mode to evaluate the profile of the gratings. Figures 2(a) and 2(b) show the cross-sectional images of the mold and imprint, respectively. An averaged cross section was used to determine the height and the period of the mold and the imprint. The averaged cross section was computed by defining a section axis and calculating for each point of the axis the average of the data that lied on the line perpendicular to the axis. This calculation has the advantage of minimizing the effect of scratches and foreign particles that would bias the peak to valley height of the grating in a simple cross-sectional measurement. The value obtained is also more representative of the whole area instead of depending on the section location. The height was computed by adding the average peak height and the average peak depth measured by the section. The period was computed by calculating the distance between peaks far apart and dividing it by the number of full oscillations.

The values for nominal and AFM-measured geometrical parameters of the specimens are reported in Table 1. Based on these parameters, nominal and AFM-measured diffraction efficiencies were numerically solved in the visible range using the rigorous coupled-wave approximation (RCWA) method [5], assuming the duty cycle of 50% in both cases. In this method, the structure is divided into several strata, and Maxwell's equations are solved for each of them to find the diffraction efficiency outside of the structure [1].

The measuring conditions such as the angle of incident light, polarization mode and refractive index of the specimens' substrates were introduced into the modeling. The structures were modeled considering the sinusoidal profiles obtained by AFM, as shown in Fig. 2(c).

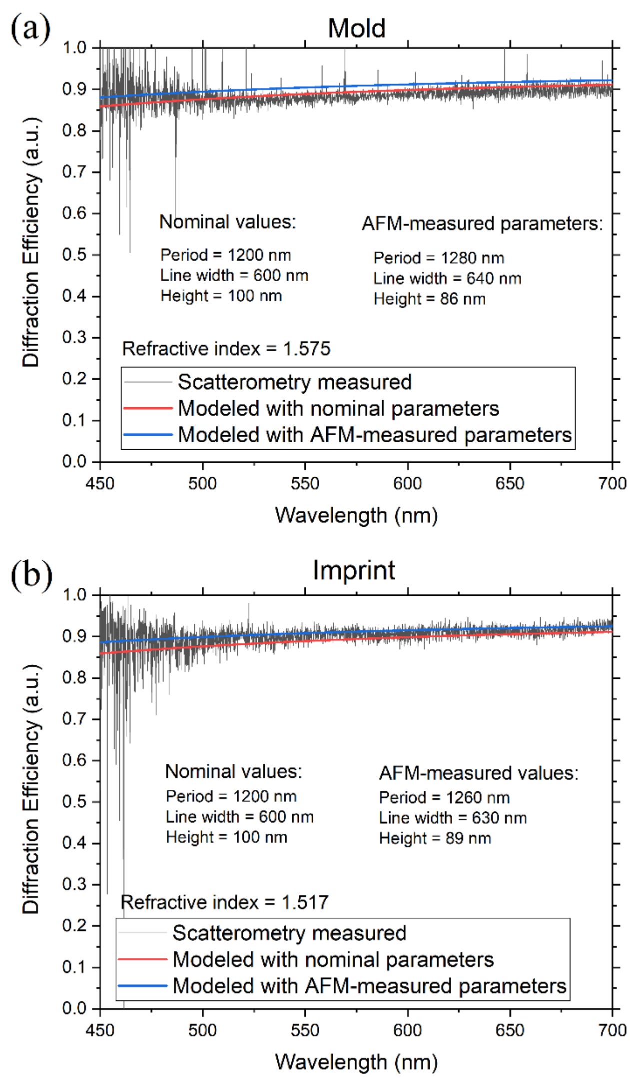

Figure 2: Measured and modeled diffraction efficiencies with TE-polarized light for the (a) mold and (b) imprint.

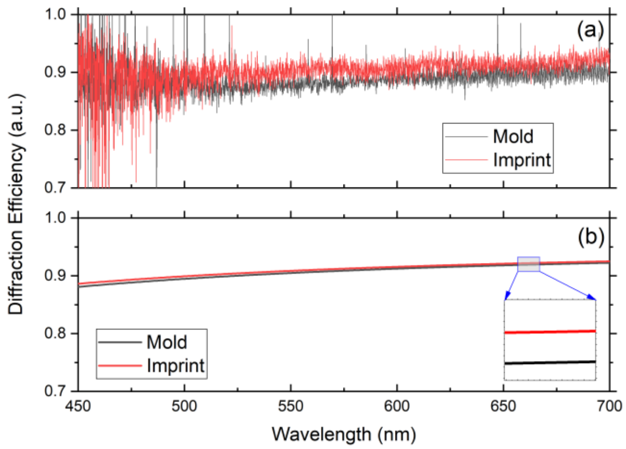

Figure 4: Diffraction efficiencies of the specimen. (a) Measured efficiencies, and (b) Simulations using AFM-measured parameters.

Table 1: Nominal and AFM-measured parameters of the specimens.

Parameter	AFM-measured		Nominal
	Mold	Imprint	
Height [nm]	86	89	100
Period [nm]	1280	1260	1200

3. RESULTS

Scatterometry-measured diffraction efficiencies along with modeled AFM-measured and nominal diffraction efficiencies for the mold and the imprint are plotted in Fig. 3. The mean percentage differences between the diffraction efficiencies modeled with nominal and AFM-measured parameters, are about 2% for the mold and imprint, verifying the validity of the AFM data. The differences between the scatterometry measurement and the AFM-measured diffraction efficiency for both specimens are within 3%, indicating that optical scatterometry is capable duplicating the AFM measurement, with an uncertainty of less than 3%.

Figure 4 shows scatterometry measurements (a) and AFM-measured modeled (b) diffraction efficiencies of the mold and imprint. The measurements imply that the diffraction efficiency of the reproduced specimen is slightly greater than the original one. Simulations verify this (the inset in Fig. 4(b). This also verifies that the replication of the specimens using the original mold was performed successfully.

4. CONCLUSIONS

Comparing the measured and modeled diffraction efficiencies of the mold and imprint reveals a high level of consistency, showing that the mold's pattern was successfully replicated to produce the imprint by R2R UV-NIL processing. Moreover, the mean percentage difference between the diffraction efficiency calculated using the AFM data, and the diffraction efficiency measured by optical scatterometry is less than 1%, which further supports the use of optical scatterometry as an alternative to AFM for evaluation of R2R-processed periodic structures.

The findings in this study can be used to reach the ultimate goal of building an in-situ self-correcting system. To achieve this goal, a digital library with all the possible structural parameters must be created. The measured data will be compared to the library to find the current parameters. In case of inconsistency with the desired parameters, the system will be used to modify the production conditions through a feedback system.

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